# Using Options to Manage Dynamic Uncertainty in Acquisition Projects

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# Using Options to Manage Dynamic Uncertainty in Acquisition Projects

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## Abstract
Uncertainty in acquisition environments can degrade performance. Traditional project planning and management tools and methods can effectively deal with uncertainties in relatively stable environments. But in more uncertain environments conditions can evolve beyond the assumptions used in pre-project planning and require major deviations from initial plans. Important uncertainties often cannot be identified and described adequately during pre-project planning to design optimal strategies. Therefore rigid project strategies prepared solely based on the most likely outcomes as perceived during pre-project planning can result in suboptimal performance. In these cases acquisition planners must explicitly incorporate flexibility into project plans to keep effective strategies available until uncertainty resolves adequately to reveal the best choice. This paper makes the case that options can provide a framework for designing, evaluating, and implementing flexible acquisition project strategies and therefore can improve project performance. However an options process model is needed that reflects options practice to improve managerial use of options. A large complex defense project illustrates the potential and challenges of options and research needs to expand and improve their use to manage uncertainty.

## Managing Uncertainty in Large Complex Defense Acquisition Projects
Maximizing the value of acquisition projects in dynamic environments is difficult partially because project managers must manage a variety of environmental and internal uncertainties as well as more common project complexities. Miller and Lessard (2000) report that success for sixty large ($985 million average cost) engineering projects, including research and development projects, depended largely on how uncertainty was managed. Many large complex defense acquisition projects also include technologies research and development in dynamic and unpredictable environments. These development efforts can pose significant risks for the entire project because their outcomes are often predecessors of major activities and any failure or delay

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in these efforts can propagate through the entire project. How can managers of large complex defense projects plan for critical uncertainties?

Development projects risk suboptimal performance if uncertainty is not explicitly incorporated into project planning. Many acquisition strategies are based on a project's characteristics and environment during front end planning. If these characteristics and environments are relatively stable initial plans can absorb changes in the project or its environment, changes in acquisition strategies are not required, and traditional pre-project planning is adequate. However, when critical parameters are difficult or impossible to accurately predict uncertainty must be managed strategically (Aaker, 1998) because changes that occur during project execution may render the best course of action, as determined during front end planning, sub-optimal (Gupta and Rosenhead, 1968). Ford, Lander, and Voyer (2002) refer to these uncertain project components and environmental impacts that only evolve adequately for strategy selection after pre-project planning as "dynamic uncertainties." and describe why they are difficult to manage.

Three characteristics of uncertainty in large complex defense projects make it difficult to manage. First, large complex development projects can be vulnerable to uncertainties because there is usually inadequate knowledge of the basic technology or its specific implementation to make accurate enough forecasts for strategy selection. In addition, they are often one-of-a-kind efforts with no opportunity to develop finely tunes routines that can be evaluated and thereby improved. Therefore, historical experience is rarely informative for future projections. Traditional project management and risk management methods that assume the past will repeat itself are inadequate for uncertain development projects to ensure project success. Second, characteristic that makes large complex defense projects difficult to manage is the long duration of such projects (e.g. 10.7 years average in the Miller and Lessard 2000 study). Long lead times in such projects make uncertainty inevitably dynamic. Components of the project strategy that are acceptable when the mission was planned may become obsolete in later stages of the project. Third, large complex defense projects constitute large, complex, and dynamic systems. Therefore, even if each component of such project systems is well understood, the overall system behavior may be difficult to understand, posing additional uncertainties on the project. These render uncertainty as a basic fact of development projects. How can defense acquisition project planners proactively prepare for uncertainty?

Designing acquisition strategies that can successfully address dynamic uncertainties is an important but difficult part of project planning. Uncertainties that cannot be identified or forecasted can only be managed reactively with adaptive systems and managers (DeMeyer, Loch, and Pich 2002). But many dynamic uncertainties can be characterized adequately to be managed proactively by anticipating alternative paths to project goals by using flexible strategies to dynamically choose the best alternative. Options can provide a framework for using flexible strategies to describe, design, evaluate, and implement specific strategies directed at specific dynamic uncertainties. Both options and decision analysis provide formal mathematical methods for valuing options that have been designed. However, less research has been directed at option design, assessment, and implementation processes for practicing planners and managers. A lack of structured methods and tools that can guide project planners in building flexible project plans to manage dynamic complexity remains a barrier to improved acquisition project management. Here options are described and evaluated as a tool for managing dynamic uncertainty from this managerial perspective. We hypothesize that the lack of an options process theory that resembles options practice constrains the description, evaluation, and advancement of options to improve acquisition.

To specify, clarify, and support our hypothesis the strategic approach to managing uncertainty and it's implementation in defense acquisition if followed by a description of options from a managerial process perspective. One use of options for procurement in a large complex defense project is described as the basis for assessing the potential of options and the differences between options practice and available theories to identify research needs to improve acquisition planning and management.

## Traditional Planning Tools to Manage Uncertainty

Strategic management, pre-project planning, and risk management provide planning tools and methods that can be used to address uncertainty: The relevant portions of these theories and their use by defense agencies are briefly described and evaluated to establish the available models of options use to manage dynamic project uncertainty in large complex defense projects.

Strategic management explicitly addresses the management of uncertainty through strategy planning that includes flexibility and strategic adaptation after initial strategy selection (Mintzberg 1978, McGrath and MacMillan 2000). Although strategic management focuses on ongoing enterprises, uncertainty must also be explicitly incorporated into project strategies to maximize performance (Miller and Lessard, 2000, Aldrich, 1979). Strategic planning integrates a response to environmental opportunities and threats with internal strengths and weaknesses in strategic plans (Aaker 1998). that are then developed into specific projects (Mintzberg, 1993). Strategic adaptation explicitly incorporates uncertainty planning by updating strategies continuously and remaining flexible (Porter, 1980). Processes have been developed for ongoing enterprises at relatively aggregate levels, but these concepts have not been developed into implementable processes for managing projects.

Increasing complexity and dynamics of large public acquisition projects have shown that rigid strategic planning methods to be inadequate (Hughes 1998). As a result several federal agencies (e.g. DoD and NASA) abandoned rigid approaches as early as 1960s in favor of a more strategic adaptive approach (Sayles and Chandler, 1971, DoD 2001, DoE 2000, DoN 2001). For example, Department of Defense (DoD 1996) Regulation 5000.2-R requires a phased decision making process and the parallel development of multiple concepts in acquisition strategies with exit criteria reviews at each phase. These provide options to abandon portions of projects as a means of strategic adaptation if the objectives can no longer be justified in the light of unfolding events. Similarly, incremental development provides options to incorporate new ideas in response to future needs.

Pre-project planning is a process for selecting an optimal project strategy (Mintzberg, 1978) and is widely used by industry (CII 1995, CH2MHill 1996) and defense agencies (DoD, 1996; DoE, 2000; DoN, 2001). Pre-project planning compares alternative technologies, sites, etc. to identify the best feasible project strategy within project constraints. Pre-project planning is effective in some contexts, but assumes that planners are fully informed about all aspects of the project and that the project environment is sufficiently stable or at least predictable (Mintzberg, 1978) Therefore, pre-project planning does not provide the flexibility required to successfully manage the dynamic complexities inherent in many defense projects.

Risk management tools and methods are used widely used by industry (CII, 1989; Chapman and Ward, 1997; Koller, 1999) and defense agencies (DoD, 2001; DoE, 2000; DoN, 2001) to manage project uncertainties by identifying critical risks to marshal resources for absorbing the consequences of uncertainty resolution that threaten project performance and by developing contingency plans. Both methods react to uncertainties after they resolve in undesired ways. In marshalling resources risk management aggregates risks to assess their impacts and thereby estimate slack resource requirements. While useful for analysis and modeling, the aggregation of risks is diametrically opposed to the reductionist approach used by managers to isolate specific individual critical uncertainties for management. While critical to complete project management and possibly used with options, the identification of critical risks and contingency planning are not operationally developed in risk management to provide managers guidance concerning how to use flexibility to improve project performance. Some defense organizations have recognized this need, requiring the analysis of projects on a continuous basis to update their acquisition strategies and detect the need for strategic adaptation (DoD 1996, DoN 2001, DoD 2001).

As prescribed by defense agencies and industry strategic management provides general guidelines for project flexibility but no operational processes, methods, or tools for using options to manage dynamic project uncertainty. Developing flexible strategic plans for projects and adapting to changes has not been operationalized adequately. Pre-project planning and risk management also do not provide operational processes to proactively use flexibility to manage projects. An operational process for options use in projects would reflect managerial practice and include option types beyond those suggested in existing guidelines. The lack of such a model constrains the effective use and improvement of flexible strategies to manage dynamic uncertainties in large complex acquisition projects.

## Options as Tools for Strategically Managing Dynamic Uncertainty

One means of achieving flexibility to address dynamic complexity is to delay committing to a strategy until uncertainty resolves, new information becomes available, and the better strategy is clearer (Gupta and Rosenhead, 1968). For example, Ward, Liker, Cristiano, and Sobek (1995) report how delaying the selection of automobile systems creats a competitive advantage for Toyota in time-to-market and quality. Options structure managerial flexibility into delayed opportunities without obligations to change strategies to improve performance. Options add value by allowing managers to capture more benefits or sell risks depending on how one or more uncertain parameters behave. For example, a contract clause permitting the termination of the contract if a critical technology is not developed provides the government with an opportunity (but not the obligation) to terminate depending on how the technology feasability uncertainty is resolved. Option taxonomies have been based on the nature of the managed asset, the objective of the management (risk mitigation or increased benefits), the timing of delayed strategy selection decisions and uncertainty evolution, and actions taken on strategies (e.g. abandon, expand, switch, etc.). Several authors catagorize and describe these classifications (see Trigeorgis 1996) and general guidelines for contracting have been codified in federal acquisition regulations (FAR subpart 17.2). In contrast, a managerial process approach is adopted here as the basis for investigating options potential, challenges, and research needs.

Despite the wide use of options by acquisition project practitioners (Miller and Lessard 2000) few options processes are described in the literature, and most of those that exist are normative (e.g. Amram and Kulatilaka 1999). Based on fieldwork at the project described later, a typical process begins when a manager recognizes (perhaps through risk assessment) that the value of a managed asset may be significantly impacted by how a relatively unpredictable parameter behaves in the future. For example a defense project manager may recognize that the costs and planned development of a specialized weapon (the asset) may depend on the design capabilities of a critical vendor after the end of an existing contract (the uncertain parameter). Managers recognize the need for options when a possible resolution of uncertainty (a scenario) using a basic strategy generates a performance scenario to be avoided (e.g. large costs) or captured (e.g. improved product performance)[3]. In the example the depletion of design capacity could increase future costs beyond budgets or constrain weapon development, or both. Alternative strategies that could improve performance under specific uncertainty resolution scenarios are then designed. Examples for the weapons system that could improve performance if design capacity degraded could include contracting for the right to continue design after the current contract or guaranteeing employment of critical employees. Option designs include specific decision rules for implementation that describe the conditions that trigger a change in strategy from the basic strategy to an alternative strategy. Designing an option requires specifying basic and alternative strategies and the decision rule. Options are implemented by monitoring the uncertain parameters, analyzing them as necessary to determine the status of the trigger, and changing strategies if indicated.

Options are valuable only when the benefits of owning the option exceed the costs. Options can provide a wide variety of benefits, including improvements in economic performance, stronger strategic position, broader managerial perspectives, expanded planning processes, and increased productivity. Options also generate costs, most visibly in financial terms. Both initially purchasing the opportunity to choose strategies in the future and implementing strategy changes can incur costs. In the weapons example an extension clause might increase the contract price and include computer upgrades at government expense if the clause is invoked. The asymmetry due to having the right but not the obligation to change strategies lies at the heart of the option's value (Trigeorgis, 1996). The economic valuation of options as a basis for strategy selection has been a primary focus of options research. Valuation methods for real assets compare net asset values with a specific option strategy to asset values using a rigid strategy to estimate option values. Valuation using decision analysis techniques use expert opinions of the probabilities of discrete uncertainty resolution scenarios at discrete times (e.g. contract dates) and include differences in individual value systems (Howard 1988, 1976). Valuation using real options theory models asset value evolution continuously over time (e.g. based on market prices) based on historic behavior and can value frequent strategy change opportunities as well as those that occur at discrete times in the future (Dixit and Pindyck 1994, Trigeorgis 1996).

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[3] Rigid alternatives that do not include options may also be considered, but are assumed to be judged sub-optimal.

Many acquisition project managers recognize the potential value of flexibility in managing dynamic uncertainties and use options. However, as will be illustrated, the practice is rarely structured into the frameworks developed by options theoreticians. Theories of managing uncertainty and options in particular do not reflect options practice by acquisition planners. This may be due to the complex, multi-dimensional nature of actual option settings, the difficulties of integrating widely varying data types for formal analysis, and the resulting informal and tacit processes used by practitioners. The process gap between options theory and options practice limits the description, evaluation, and improvement of options use practices.

## Options in Procurement for the National Ignition Facility

The National Ignition Facility (NIF) project is being developed by The Lawrence Livermore National Laboratory (LLNL) under contract with the U.S. Department of Energy. DOE's goal is to simulate, in a laboratory setting, the thermonuclear conditions created in nuclear explosions. NIF will be the world's largest experimental fusion facility, using 192 lasers to compress and heat a small capsule of material to fusion ignition. The project budget is $2.248 billion to be spent over approximately eleven years (Moses 2002). Project success depends on several large simultaneous research and development efforts to produce these special systems.

Data was collected about the use of options to manage uncertainty in the NIF project by observing four public presentations on the project by DOE and LLNL management, reviewing selected project documents, interviewing the DOE project manager and LLNL project and procurement managers, and visiting the site twice, including tours of the facility while under construction. NIF managers were found to use options (although they do not typically use that term) to manage many of the large uncertainties inherent in the project. The LLNL project manager attributed the management team's frequent use of flexibility (including options) to their focus on project objectives instead of specific solutions to project needs. This allows managers to identify multiple potential strategies and scenarios to success (Moses 2001). These strategy:scenario sets were used to design options. Several principles for managing uncertainty guided procurement strategies on the NIF project. Examples include having two or more vendors for all major components to reduce the risk of inflated prices by a sole supplier (Moses 2002) and LLNL avoiding a manufacturing role to reduce the risks due to uncertain project funding and schedules. LLNL preferred to contribute in its areas of strength (scientific expertise and funding) and structure procurement strategies to focus vendor efforts on their strengths (e.g. technology development and manufacturing).

**Laser Glass Procurement: An Example of Applying Options in Technology Development**

The NIF laser glass production strategy illustrates the use of options to address a common but important large acquisition project question: How many parallel development efforts should be supported? Many factors impacted laser glass production in addition to the options strategy. Some of these factors will be identified to illustrate the complexity of options use in practice. However we focus on the options aspects of laser glass procurement, as the details of other aspects or their impacts on laser glass production are beyond the scope of this paper.

NIF will spend more than $350 million to produce over 3,000 pieces of laser glass, weighing about 150 pound each[4]. Laser glass begins as slabs of very high quality glass called "blanks." The large volume of blanks and project schedule and budget constraints required a production rate thirty times larger and five times cheaper than was used on prototype lasers, precluding the use of traditional batch methods and requiring the development of a new glass production technology and manufacturing facilities. Glass vendors could not justify funding the development. Therefore NIF invested in glass production technology development (Campbell, 2001). The development of high-volume continuous-melting glass production process included at least two critical uncertainties, corresponding to whether the technology could make the long blocks of glass that would be cut into laser glass blanks and whether the quality of the glass would be acceptable. The threat posed by these uncertainties was that, if technology development efforts failed in either way the project could be delayed too far to meet its deadline and would incur very high unbudgeted costs. Although LLNL had established relationships with experienced laser glass vendors, none could guarantee successful development a priori. Therefore, it became clear during laser glass procurement planning in 1994_that alternatives to a one-vendor strategy should be considered.

LLNL considered two types of procurement strategy for the glass production technology development. In a base strategy LLNL would invest in a single glass production technology development effort, helping as possible and hoping for a successful development. A different strategy would simultaneously invest in two independent development efforts by two glass producers, increasing the likelihood that at least one of the producers would be successful. If

[4] The parallel development of a French facility similar to NIF that would also need laser glass increased demand and

only one technology effort was successful this strategy allowed LLNL to abandon the failed development effort, use the successful one, and avoid the consequences of having no successful glass production system at the end of the initial investment period[5]. In this example the dynamic uncertainty is the likelihood of a vendor successfully developing a feasible glass production technology with the required quality. The cost of the basic strategy is the cost of investing in one vendor (approximately $12 million). Investing in multiple vendors would purchase NIF opportunities to proceed with successful vendors at two points in time, when each of the uncertainties were resolved. The option costs are the additional costs of investing in each additional vendor up to the uncertainty resolution times (approximately $12 million each). The flexible strategy can be structured as two options to abandon an unsuccessful vendor when the technology feasibility and glass quality uncertainties resolve. Does the one-vendor or two-vendor strategy best serve NIF?

NIF managers considered the multiple-vendor strategy attractive for both economic and non-economic reasons (e.g. generating competition between vendors). Despite a plethora of factors that influenced strategy attractiveness, the analysis that valued the option and drove strategy selection centered on the following comparison of strategy:scenario sets. If a single vendor was selected the development might succeed. But if the single vendor failed to develop a glass production system in the initial investment time the costs to the project in time, money, and political consequences would prevent the project from meeting its targets. In contrast, if two vendors were selected none, one, or two could succeed. The likelihood of two failures was

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schedule uncertainty.

considered low. Exactly one success would allow NIF to use its option by abandoning the unsuccessful vendor, and two successes would provide manufacturing and pricing flexibility in addition to NIF's minimum needs. The avoided costs of failure if investments were made in two vendors were (informally) estimated to greatly exceed the additional cost of investing in a second vendor, even if the avoided costs were discounted at any reasonable rate to account for the time value of money and other benefits. Therefore the option was worth more to the project than its cost. Based on this reasoning, in 1994 the DOE and LLNL decided to simultaneously invest in two vendors and in 1995 contracted with two potential vendors to support parallel development efforts without further commitments by LLNL or DOE. This strategy purchased two options to abandon a failed development (if one occurred) and continue to support a successful development (if one occurred) when the technology feasibility and quality uncertainties resolved, thereby avoiding the costs of failed development.

The uncertainty about technology viability was resolved in early 1999 when both vendors successfully produced pilot runs of glass using a continuous flow process. Due largely to the remaining quality uncertainty NIF chose to not abandon either vendor. Quality uncertainty was resolved near the end of 2000 when both vendors also demonstrated the ability to generate the required glass quality. NIF chose to continue with both vendors. If exactly one vendor had failed to develop a successful production technology the option would have operated as designed and described above. Because both vendors succeeded NIF purchased valuable production and pricing flexibility with which it can manage other project uncertainties (e.g. schedule). The costs

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[5] Other alternatives available such as adding investment or postponing the decision beyond the initial investment period provided additional options but are not considered here for clarity. Kemna (1993) provides evidence that focusing on a few options captures the majority of potential benefit to practicing managers using options.

avoided remain significant, albeit less than those saved in case of a development failure. The NIF laser glass production option illustrates how options have been used to increase project value and the difficulty of rigorously addressing relatively simple but important procurement questions (e.g. how many vendors). The next section discusses the challenges in applying options theories to project planning in large complex defense projects and suggests research needs.

## Discussion

An acquisition strategist might ask several questions concerning the NIF laser glass procurement strategy. First, how many vendors is the optimal number for NIF to invest in? Precluding clairvoyant planning that could have perfectly predicted the success of a single vendor, it appears that the NIF management chose the right strategy. But if, in the extreme, the likelihood that a single vendor would succeed was believed to be 99% and the added cost of a second vendor was very high perhaps the option should not have been purchased and a single-vendor strategy would have been preferred. On the other hand, what if both vendors had failed? Perhaps NIF should have invested in more than two vendors. Would strategies in addition to those considered have added more value to the project? More generally, how does the structure of the project and candidate option strategy impact its value and thereby strategy selection?

Answers to these questions for acquisition projects are not obvious or easily obtained, but depend largely on the probabilities of success, costs, and their analysis. Researchers have proposed methods of economically valuing parallel development strategies that may be applicable to the multiple-vendor problem described here (Mandlebaum and Buzacott 1990, Ding and Eliashberg 2002). But the simplifying assumptions required for mathematical tractability prevent these models from realistically modeling the complexities inherent in managing uncertainty in large development projects. Questions also arise concerning how the strategies were designed. What other strategies should have been considered? How do acquisition planners know whether all potentially valuable strategies have been identified? Howard (1988) describes a potentially useful strategy design tool but does not include it in a complete options process. A theory of options practice is needed to relate current options theories and practice.

Planning researchers might asses NIF's use of options with existing theories. The domains that contribute to options theories provide a basis for assessing NIF's use of options. Laser glass procurement in the NIF project used some of the methods and tools prescribed by strategic management. NIF managers surveyed the project environment to identify uncertainties that threatened project success (e.g. undeveloped glass production technology). Managers also assessed NIF's internal strengths (e.g. science) and weaknesses (e.g. manufacturing) as a part of strategy development. However there was no evidence found that the team identified all potentially valuable strategies or was able to test how well the selected strategies addressed the uncertainties compared to alternate strategies. Laser glass procurement in the NIF project focused on flexibility (ala DoD guidelines), using a reductionist approach to isolate and manage key individual uncertainties. The observed use of options does not closely match options theory. This supports our hypothesis that a structured process for the design, assessment, and use of options that resembles practice is needed to improve options use.

This paper has described dynamic uncertainties as a particularly difficult challenge in strategically planning large complex defense projects. Traditional methods and tools for managing uncertainty were reviewed and found unable to adequately address dynamic uncertainties. Options are proposed as a means of proactively managing dynamic uncertainty by providing a framework for structuring the management problem, potential strategic responses, and valuation for strategy selection. Deficiencies in options theories for application are identified. An example of the use of options for procurement at a large defense project illustrates the potential benefits and challenges of using options in practice. The lack of structured processes and tools for designing, valuing, and implementing options by practitioners limits their assessment and improvement. These tools and processes would also integrate flexible strategies with existing project planning and management tools and thereby expand the strategic project planning domains. Applying such tools and processes would increase project values in large complex defense projects.

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